

Materials Theory Institute: Hopping Conductivity in Granular Metals

Scientific Achievement

There is a new emerging sub-class of disordered materials such as nanocrystals or arrays of metallic, superconducting or semiconducting granules which captures all the properties that usual disordered conductors demonstrate, but at same time demonstrates a richness of new behaviors that allows for a successful theoretical description. By considering a regular array of metallic granules coupled to each other by tunable tunneling junctions and changing the coupling strength, one can drive a metallic nanocrystal through the entire range of conducting behaviors from a good metal at strong coupling- to an insulator with weak coupling between the granules. We developed a theory to elucidate the transport properties of the insulating state and solved a nearly 30 year old puzzle. We demonstrated that nanocrystals in the insulating state can show variable range hopping-like conductivity. Indeed, depending on the particular temperature range, hopping conductivity is governed by either elastic electron tunneling (at lowest temperatures) or by the process of inelastic co-tunneling at elevated temperatures.

The main problem of hopping conductivity in granular metals was to understand how electron tunneling can occur over distances well exceeding the average granule size in a dense granular array. The elastic co-tunneling mechanism transfers the charge via tunneling of an electron through an intermediate virtual state on the granule such that the electron comes out with the same energy it came in. In the second mechanism – inelastic co-tunneling – an electron that exits the dot has a different energy. After such a tunneling process, an electron-hole excitation is left in the granule which absorbs the energy difference. Both these processes occur via the classically inaccessible intermediate states.

Significance

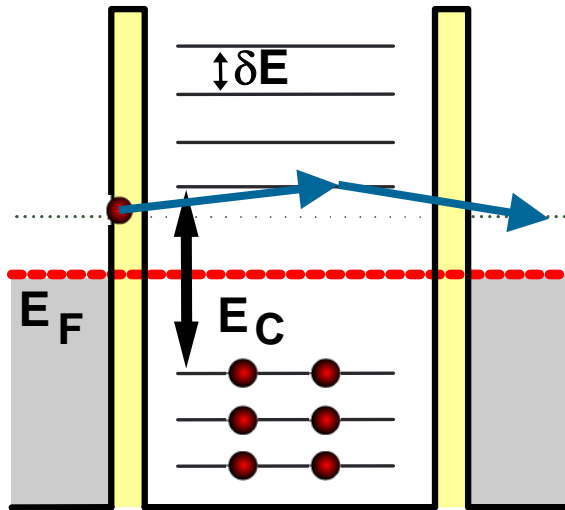
This work opens a new route for a large scale research project aimed at understanding the most fundamental properties of mesoscopic disordered solids by offering, for the first time, a well defined model of a glassy state and a liquid-glass transition, which is amenable to analytical treatment. Our developed approach enables a detailed investigation of the metal-to insulator transition in granular materials, in particular, the behavior of the nonlinear conductivity close to the transition. The nonlinearity could be anomalously strong, paving the way for a number of applications. Based on our new approach, we plan to construct a comprehensive theory related to transport properties in arrays of semiconductor quantum dots. The results of our research are described in the following publications: I. S. Beloborodov, A. V. Lopatin, and V. M. Vinokur, Phys. Rev. B **72**, 125121 (2005) and T. B. Tran, I. S. Beloborodov, X. M. Lin, T. P. Bigioni, V. M. Vinokur, and H. M. Jaeger, Phys. Rev. Lett. **95**, 076806 (2005).

Performers

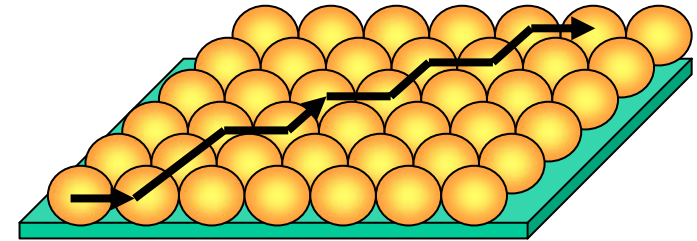
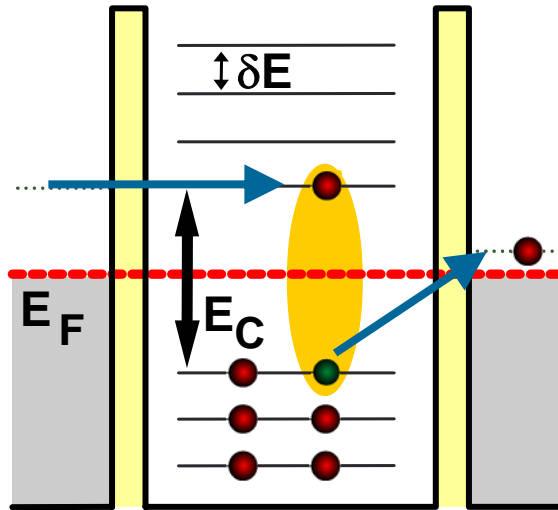
I Beloborodov, A. Lopatin, and V. Vinokur (ANL-MSD)

Hopping conductivity in granular metals

elastic



inelastic



co-tunneling processes controlling variable range hopping conductivity in granular metals at very low and moderate temperatures respectively.

Experiment

